Fasciotomy Rates in Operations Enduring Freedom and Iraqi Freedom: Association with Injury Severity and Tourniquet Use

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Objective: To compare fasciotomy rates and Injury Severity Scores (ISSs) before and after tourniquets were fielded for combat casualties in March 2005.

Methods: A military trauma registry was used to identify 4332 casualties with limb injury between 2003 and 2006. Descriptive statistics and regression analysis were used to compare changes in ISSs, limb Abbreviated Injury Scale (AIS) scores, and fasciotomy rates. An item of specific interest was whether changes in fasciotomy rates occurred before and after March 2005, when tourniquets were fielded. Therefore, this time point served as a specific comparator in the statistical analyses.

Results: Among the 4332 limb casualties, 669 (15%) underwent fasciotomy. The ISS doubled (100% increase) during the study. Limb AIS increased 35%. The increase in limb AIS constituted most of the increase in ISS. Monthly fasciotomy rates increased 500% (5% to 30%) during the study. When controlling injury severity (both AIS and ISS), fasciotomy rates tripled (200% increase); but when comparing fasciotomy before and after tourniquet fielding by AIS and ISS, rates only doubled (100% increase). On logistic regression for predicting fasciotomy, the model was unable to determine a good fit for the data because the variables were not significant except weakly for injury severity.

Conclusions: During the period of the study, fasciotomy rates increased as a result of a combination of factors: increasing injury severity, increasing use of tourniquets, and increased awareness of the need to perform prophylactic fasciotomy. Further research should be aimed at determining what the optimum rate of fasciotomy is in such an environment.

Key Words: hemorrhage control, compartment syndrome, ischemia, reperfusion, resuscitation

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INTRODUCTION

Extremity trauma in US military personnel is common, disabling, and costly.[1–4] Most wounds, 54%, sustained in the current war are limb injuries, an incidence that is similar to prior wars.[2] The severity of combat limb wounds is high. For example, 82% of all limb fractures are open fractures.[3] However, although limb injury rates remain high, casualty survival has also reached a historic high; over 90% of combat casualties now survive.[4–6]

Although emergency tourniquets are rarely used in civilian trauma care, more evidence supports their use for hemorrhage control in combat casualties.[7–9] With the recent widespread reintroduction of emergency tourniquets onto the battlefield, we have continued to survey data for possible negative effects in their use such as compartment syndrome and fasciotomy as reported in the past.[10,11] Tourniquets were issued to small groups of soldiers in 2003 to 2004[9] and subsequently were issued systematically to all individual US service personnel deploying after March 31, 2005. Our initial study of the use of tourniquets in 232 casualties indicated a low fasciotomy rate,[7] but for all casualties, actual fasciotomy

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rates were unknown before and after widespread tourniquet fielding. Additionally, fasciotomy rates and complications have been a subject of much discussion as well as educational initiatives.[12] Because our initial survey of 232 casualties indicated a major lifesaving benefit with tourniquet use[8] without an increased fasciotomy rate,[7] we hypothesized that the fasciotomy rate was unchanged during this conflict. Factors that also affect compartment syndrome could be injury severity, changing clinical practice in evaluation and resuscitation, and changes in provider awareness of compartment syndrome and thresholds for fasciotomy.[13–17] We included these variables in our analysis. The purpose of the present study is to compare fasciotomy rates, casualty injury severity, and limb injury severity before and after tourniquet fielding.

METHODS

Study Design

We retrospectively surveyed war casualty data at the Landstuhl Regional Medical Center, the main through-point for US casualty evacuation. In this survey, deidentified data (date of injury, military service, casualty type, theater of injury, fasciotomy codes, and injury severity codes) for each casualty were obtained from the Joint Theater Trauma Registry. The Joint Theater Trauma Registry, a database that includes data on war casualties from the current conflict who survived to arrive at the first hospital, is stewarded by the US Army Institute of Surgical Research at Fort Sam Houston, TX. The present study is a performance improvement project aimed at detecting opportunities to refine combat casualty care. The protocol was approved by the Institutional Review Board.

Definitions

Critical data definitions from the Joint Theater Trauma Registry used in our analysis include casualty, casualty type, casualty service, Abbreviated Injury Score (AIS), Injury Severity Score (ISS), fasciotomy, and major limb trauma.

- A casualty is defined as any US service person injured in the current war who survived to arrive at the Landstuhl Regional Medical Center during the survey.
- Casualty type refers to the type of injury sustained; this study focused on orthopaedic injuries.
- Casualty service refers to the military branch: US Army, US Marines, and US Air Force.
- The AIS is a two-component code of anatomic tissue damage from injury with a linked description (2005 version) that represents a threat-to-life score. It consists of a six-digit integer and a single-digit integer.[18] The six-digit code is linked to an injury description, whereas the single-digit number ranks injury severity from 1 (minor) to 6 (unsurvivable). If a casualty sustained multiple limb injuries; the maximum limb AIS was the one studied. We used the six-digit AIS code that starts with the anatomic regions to identify the limb casualties (7 for upper and 8 for lower extremities), but the six-digit code itself was not in the extracted data set. Examples of AIS injuries are listed in Table 1.

TABLE 1. Examples of AIS Injuries and Ranks

AIS Rank	Injury Description
1	Soft tissue (eg, muscle) wound of the leg without a vessel injury or fracture
2	Traumatic foot amputation
3	Traumatic below-knee amputation at or above the ankle
4	Traumatic above-knee amputation
5	Open, unstable pelvic ring fracture

AIS, Abbreviated Injury Score.

- The ISS is an integer anatomic injury code used for overall casualty with multiple injuries (2005 version).
- Fasciotomy uses one (or more) limb fasciotomy procedure codes (International Classification of Diseases, 9th Revision, 83.14 [fasciotomy, division of fascia], or 83.09 [other incision of soft tissue, incision of fascia, excluding incision of skin and subcutaneous tissue alone, 86.01–86.09]). Fasciotomies took place before the patient arrived or at Landstuhl. Our operational definition of fasciotomy in the present study excludes hand and foot fasciotomies. Both prophylactic and therapeutic procedures for compartment syndrome are included in these codes.
- Major limb trauma included fractures, crushing injuries, dislocations, open wounds, amputations, and injuries to blood vessels and nerves with a score of AIS 3 or higher. Such trauma indicated emergency surgery.

Study Population, Study Group, Fasciotomy Subgroup, and Study Period

The population of interest was US service personnel injured in the current war limited to those who arrived at Landstuhl. Most casualties are treated at Landstuhl before their return to the United States, and the site provided the best location to survey the largest uniform population of hospitalized casualties. Because we were interested in limb (orthopaedic) casualties, we included those with an AIS code of 7 (upper extremity) or 8 (lower extremity). The 7 or 8 codes do not specifically exclude those who also had external (skin) or thermal injury (9) codes such as burns or whole-body injury (0) codes. There were no unsurvivable limb injuries (AIS 6). We excluded non-US personnel and six casualties sent through a naval hospital in Spain. The number of limb casualties (persons) who arrived alive at Landstuhl was 4332; this study group was compared with the subgroup of 669 fasciotomy casualties. The study period was four calendar years, 2003 to 2006.

Statistical Analysis

We used descriptive statistics for demographic data, linear regression for trend data over time (days), the Mantel-Haenszel chi square test for proportion trends by year, and regression for variable association (linear for continuous and logistic for yes/no variables). We used the following software: Excel (Version 97; Microsoft, Redmond, WA), SAS/STAT (Version 9.1; SAS Institute, Cary, NC), and SigmaPlot (Version 10; Systat Software, Point Richmond, CA). A P value of 0.05 was considered significant.

RESULTS

Results for All Limb Casualties

The results for the 4332 casualties arriving alive at Landstuhl Medical Center are as follows.

The proportion of casualties with major limb trauma (AIS 3 to 5), shown in Figure 1, increased gradually each year during the study ($P < 0.001$).

For the 4332 limb casualties, the limb injury severity (AIS) increased gradually over time ($P < 0.001$ on linear regression, $r = 0.1652$). The change from beginning to end of the regression line was a 35% increase (1.4-fold; range, 1.7 to 2.3). The median monthly AIS increased 50% from 2 to 3 during the study.

The overall injury severity (ISS) for the 4332 limb casualties doubled gradually over time: 100% (range, 6 to 12, $P < 0.001$ on linear regression, $r = 0.2005$). The median monthly ISS increased 150% from 4 to 10 during the study. The AIS increase of 50% (2 to 3) constituted 83% of the ISS increase of 6 (range, 4 to 10).

Results for Fasciotomy Subgroup: 669 Surviving Casualties With Limb Injury and Fasciotomy

For the 669 casualties who underwent fasciotomy, the results were as follows

The proportion with major limb trauma (AIS 3 to 5) increased gradually each year during the study ($P < 0.001$; see Fig. 2). In every year, the majority of casualties with fasciotomy had major limb trauma; and, compared with casualties without fasciotomies, these casualties had a higher incidence of major limb trauma.

Limb injury severity (AIS) also increased gradually over time in the 669 fasciotomy patients ($P < 0.001$ on linear regression, $r = 0.1292$). The change from beginning to end of the regression line was a 20% increase (1.2-fold; range, 2.3 to 2.8). Casualties with fasciotomies survived with worse limb injuries over time. The median monthly AIS increased 50% from 2 to 3 during the study.

A similar gradual increase was observed in the overall injury severity (ISS) over time in casualties with fasciotomies ($P < 0.001$ on linear regression, $r = 0.1520$). The change of the regression line beginning to end was a 70% increase (1.7-fold; range, 10 to 17). The median monthly ISS increased 189% from 4.5 to 13 during the study. The AIS increase of 50% (2 to 3) constituted 59% of the ISS increase of 8.5 (range, 4.5 to 13). The AIS increase constituted most of the ISS increase in both the subgroup (669 casualties with fasciotomies) and the main group (4332 casualties with limb injuries).

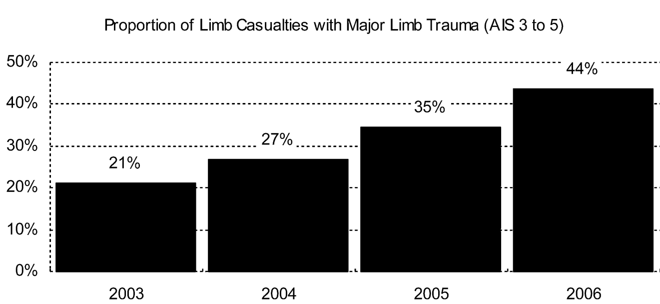

FIGURE 1. Annual proportions of casualties with major limb trauma.

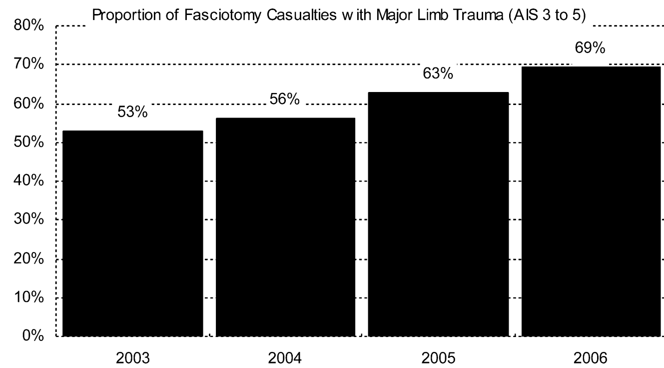

FIGURE 2. Annual proportions of casualties with fasciotomy who had major limb trauma.

Fasciotomy Rates Before and After Tourniquet Fielding

The results of the fasciotomy rates before and after tourniquet fielding were as follows

For the 4332 US war casualties with limb injuries and 669 casualties with fasciotomies before arrival or at the Landstuhl Regional Medical Center, the fasciotomy rate was 15% (669 of 4332) for the study period.

Monthly fasciotomy rates (Fig. 3) increased from before to after tourniquet fielding ($P < 0.001$). The minimum rate after tourniquet fielding (16%) was near the maximum before fielding (18%), and the 95% confidence intervals did not overlap.

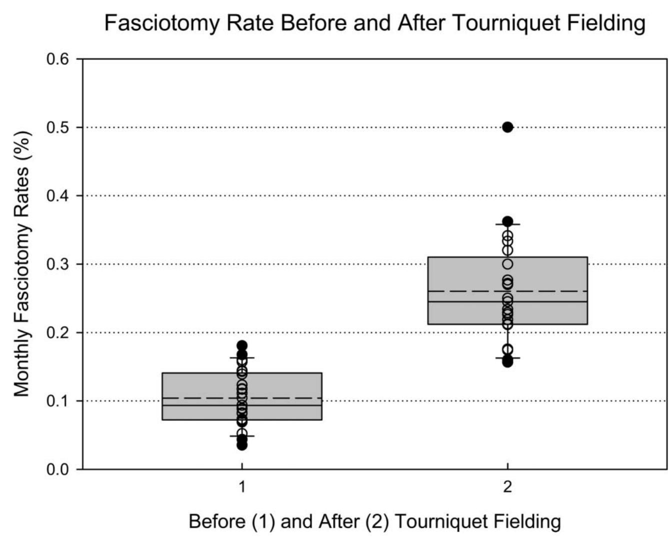

FIGURE 3. Monthly fasciotomy rates before and after tourniquet fielding. Vertical dot plots have data points as dots with black outliers. Box plots have parameters as lines; and the box represents the 25% and 75% confidence limits, the whiskers represent the 95% confidence limits, the mean is the dashed line, and the median is the solid line.

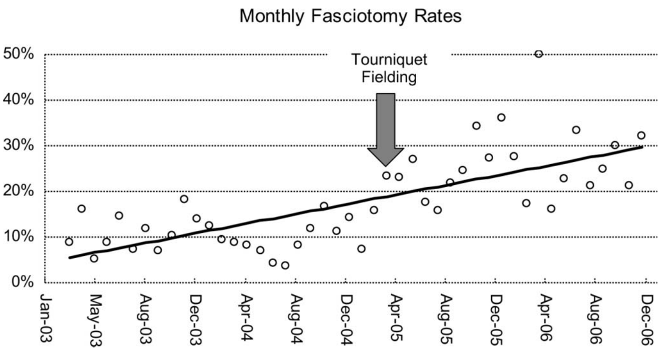

FIGURE 4. Fasciotomy rate by month. Tourniquet fielding occurred at one time (arrow). The regression line for rates over time before and after tourniquet fielding is shown ($r = 0.3904$).

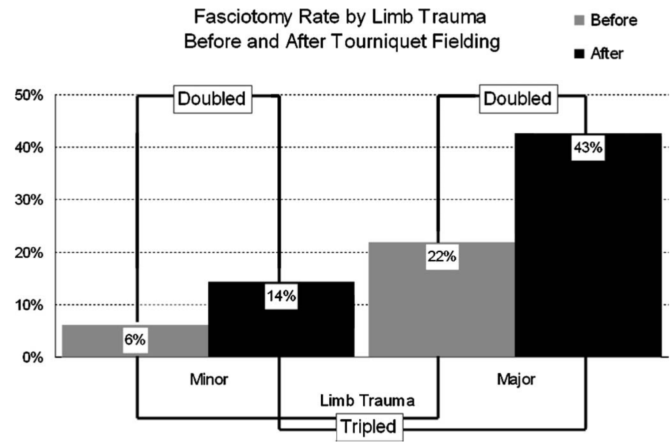

FIGURE 5. Fasciotomy rate before and after tourniquet fielding by Injury Severity Score (ISS).

Linear regression of the fasciotomy rates by month showed that the monthly fasciotomy rate increased 500% (sixfold, from 5 to 30; $P = 0.007$), as shown in Figure 4.

A comparison of fasciotomy rates by ISS showed that fasciotomy rates doubled (100% increase) after tourniquet fielding for every ISS range (Fig. 5). From lowest to highest ISS range, the fasciotomy rate tripled (200% increase) with increased ISS both before (range, 6 to 20) and after (range, 13 to 40) tourniquet fielding (Table 2).

The fasciotomy rate doubled (100% increase) after tourniquet fielding for both minor and major limb trauma (ranges, 6 to 14 before; 22 to 43 after), as shown in Figure 6. From minor to major limb trauma, the fasciotomy rate tripled (200% increase) with increased limb trauma both before and after tourniquet fielding (ranges, 6 to 22 before; 14 to 43 after). The greater increase with injury severity than tourniquet use indicates that injury severity contributed more to fasciotomy rates than tourniquet use. A comparison of fasciotomy rates by each limb AIS showed similar results as the comparison by minor and major limb trauma (Table 3).

An attempted logistic regression for predicting fasciotomy was unable to find a good fit for the data and that the variables were all (ISS, AIS, fasciotomy, and date) significantly associated, albeit not strongly ($P < 0.001$; $r < 0.268$) (Table 4).

DISCUSSION

The present study highlights the increase in conflict-related extremity injuries. The present work surveyed the largest fasciotomy cohort to date and offers possible associations among injury severity, fasciotomy rates, and tourniquet use. With improved lifesaving medical care[8,19] and protection,[5,17] more survivors have more severe limb injuries and require more subsequent procedures such as fasciotomy. Similar results were seen in World War I with the introduction of the Thomas splint for prehospital treatment of open femur fractures. The case fatality rate of open femur fractures dropped precipitously from 80% to approximately 8% as a result and led to the need for new 1000-bed specialty hospitals for the treatment of survivors.[20,21] One of the unforeseen consequences of this lifesaving device was the large and costly effort needed to treat survivors in attempts to stave off disability.

The main finding of the present study was that fasciotomy rates increased from 2003 to 2006. We had not sensed that the fasciotomy rates had increased until we actually measured them. Although we were surprised by the increase, there are several reasons why this may have happened. The increase in fasciotomy rates before and after tourniquet fielding was similar to the increases in both ISS and limb AIS rates. The case survival rate for all combat casualties in the present conflict during the survey period was unchanged (at a historic high) despite the rise in ISS and perhaps the proven lifesaving benefit of tourniquets was one of the reasons for this rate.[5,6,8] We are unaware of other instances in which the use of a specific first aid device has been associated with such a distinct change in the casualty population profile.

In civilian settings with fewer cases,[22] analysis of rare tourniquet use is hampered by the need to combine study data

TABLE 2. Fasciotomy Rates by Injury Severity Score (ISS)

		ISS							
		1 to 8		9 to 15		16 to 24		Greater Than 24	
		Tourniquet Fielding							
Parameter		Before	After	Before	After	Before	After	Before	After
Fasciotomy group (no.)	669	102	87	117	178	36	58	26	65
Limb group (no.)	4,332	1694	649	746	512	15	30	20	40
Fasciotomy rate (%)	15	6	13	16	35	15	30	20	40

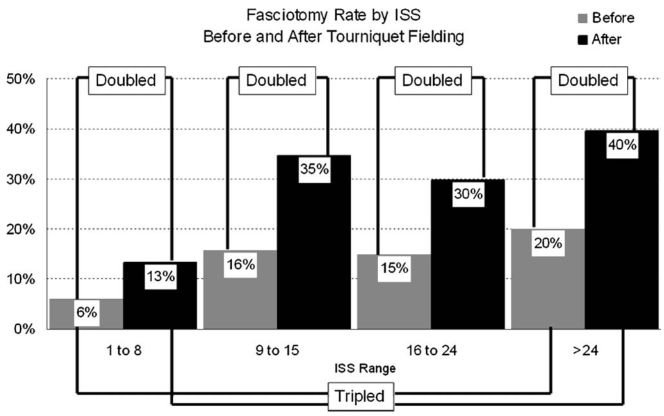

FIGURE 6. Fasciotomy rate before and after tourniquet fielding by minor and major limb trauma.

Given the constraints of the current observational study, the analysis also indicated that tourniquet fielding may be less responsible for an increase in fasciotomy rates than the actual injury severity (AIS and ISS). Both limb injury severity (AIS) and overall casualty injury severity (ISS) have increased during the current conflict. These injuries constituted the majority of the burden of injury compared with other body regions.[1–4] The limb injury severity (AIS) increase constituted most of the overall injury severity (ISS) increase. In a recent report from our institute, limb casualties compared with all other body regions used 65% of the in-patient healthcare costs and accounted for 64% of disability costs.[4] The National Trauma Data Bank indicates that the case fatality rate for ISS 1 to 8 is 0.7%, whereas the rate for ISS 9 to 15 is 1.9%. Using the National Trauma Data Bank rates as a benchmark, we would have expected mortality to increase by 1.2% when the ISS doubled from 6 to 12 in the current study. However, rather than an increase, the case fatality rate for all conflict casualties actually stayed the same at 3.7% during the study period, a rate that has been attributed to factors such as improved body armor and health care.[5,6]

TABLE 3. Fasciotomy Rates by Limb Abbreviated Injury Scale (AIS)

		AIS									
		1		2		3		4		5	
		Tourniquet Fielding									
Parameter		Before	After	Before	After	Before	After	Before	After	Before	After
Fasciotomy group (no.)	669	39	46	87	85	136	215	19	39	0	3
Limb group (no.)	4,332	1,036	429	1,071	487	632	509	71	90	3	4
Fasciotomy rate (%)	15	4	11	8	17	22	42	27	43	0	75

TABLE 4. Summary of Regression Results for All Casualties and Just Those With Fasciotomies

	Spearman's Correlation Coefficients and *P* Values	
	ISS	AIS
All casualties (n = 4332)	0.1969 < 0.0001	0.15092 < 0.0001
Casualties with fasciotomy (n = 669)	0.2003 < 0.0001	0.26784 < 0.0001

ISS, Injury Severity Score; AIS, Abbreviated Injury Score.

from many municipalities with disparate policies, training, and doctrines. The rarity of ideal opportunities to study first aid devices and policy changes (not limitations of the device itself) may help to explain why so few devices have demonstrated similar effects.[20,21] Because fasciotomy rates doubled when injury severity was controlled, surgeon willingness to perform fasciotomy appeared to be a reason for the increased fasciotomy rate. Although it was voluntary, widespread predeployment trauma training for all clinicians began in December 2005 for a January 2006 deployment and increased surgeon willingness to perform fasciotomy was emphasized. After delayed fasciotomies were needed for casualties arriving at Landstuhl, deployed surgeons were encouraged by e-mail and teleconferences in April 2006 to be more aware of the possible need to perform fasciotomies.[12] Interestingly, January and April 2006 had the highest fasciotomy rates.

The present survey had several limitations. It was not comprehensive because of database limitations, and it was a retrospective survey meant to generate hypotheses aimed at improved combat casualty care. The data have limits themselves; eg, database coding fidelity can be reliable (maximum limb AIS for a casualty) or not (which of the four limbs had the tourniquet and was that necessarily the one with the maximum limb AIS?). Although we could offer explanations on why the fasciotomy rate increased, without knowing this fact ahead of time, we could not formally design a study to test why. Time (day to day or year to year) is only a practical surrogate for evolution of care and changes of injury mechanism such as the

increasing proportion of explosions versus gunshot wounds. Current research techniques have limitations in the analysis of association versus causation.[23] One author in the present study, in his experience of 346 operating room visits during the current war, observed that almost half (14 of 30) of fasciotomies were prophylactic and not therapeutic (Kragh, Ibn Sina Hospital, Baghdad, 2006); the lack of differentiation is a current research barrier. The AIS appears to have a ceiling effect for fasciotomy because 4s or 5s indicate fasciotomy at high rates, probably for the injury itself or revascularization procedures, although many AIS 5s are too proximal for a tourniquet to fit. The risk–benefit decision strongly favors emergency tourniquet use in battle casualties.[7–9,19,24,25]

CONCLUSIONS

Based on our data, we can summarize our findings as follows: 1) ISS for limb casualty survivors increased 100% during the study; 2) limb injury severities (AIS) in survivors increased 35% during the study; 3) the increase in limb injury severity (AIS) explained most of the increase in overall injury severity (ISS); 4) fasciotomy rates for limb casualty survivors increased 500% during the study; and 5) injury severity increases explained more of the fasciotomy rate increase than other reasons such as tourniquet ischemia–reperfusion or increased surgeon willingness to perform fasciotomy (including prophylactic fasciotomy).

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